# PRELIMINARY ANALYSIS OF TECHNICAL RISK AND COST UNCERTAINTY IN SELECTED DARPA PROGRAMS

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# EXECUTIVE SUMMARY

This report documents the analytical results and conclusions of a four-month investigation of cost and uncertainty in selected DARPA programs. The analysis focuses on risk and the management of risk from a technical, cost, and schedule perspective through a comparison of DARPA experience to a large experience base of other federal programs. The results indicate that DARPA experience in the management of high technology programs can be interpreted (and to some degree of accuracy, forecasted) using this experience base. In addition, this analytical and empirical approach can be used to assist DARPA in complying with recent DOD directives to recognize risk in budgeting and planning estimates. Most importantly, the study effort demonstrates that it is possible to identify qualitative and quantitative indicators to characterize risk and to use such descriptors as the basis for risk management.

The analysis described in this report is based in large part on a data base related to federal historical experience in hundreds of R&D programs over a number of years. Using this data in concert with information related to the budgetary history of selected DARPA programs, a technique to estimate risk budgets as a function of confidence level was developed. Finally, using this technique as a point of departure, a management process to (1) integrate management input to modify and revise risk budget estimates and (2) coordinate existing cost/schedule/performance program data into the control of risk budgets was designed. The process is designed to be simple, iterative, and amenable to subjective input by management. It was also developed so as to require minimal resources to implement and to fully utilize existing DARPA management information systems upon which current programming and budgeting activities are based.

# I. INTRODUCTION

## A. SCOPE

This report documents the results of technical efforts to analyze the size and nature of cost growth and cost growth risk in selected DARPA R&D programs and to develop a recommendation for monitoring and controlling such risk. An Interim Progress Report previously submitted discussed the results of a statistical comparison of historical data related to a wide range of government R&D programs, including DARPA activities. That effort identified the development of a procedure whereby cost growth risk, expressed as a level of confidence in the adequacy of a program risk budget of a given size, could be quantitatively estimated for a set of R&D programs. This report expands on this concept and describes a management framework within which such procedures can be used to continually assess and compare cost growth risk as programs evolve in an attempt to improve DARPA capability to anticipate, understand, and mitigate the impact of uncertainty in programs characterized by risk.

## B. OBJECTIVE

This effort was conducted under the auspices of the DARPA Program Management Office. It is the responsibility of this office to plan, manage, and control, at the aggregate level, the allocation of DARPA program funds. This management responsibility is separate and distinct from the responsibilities of the technical program offices to manage projects from a technical, cost, and schedule point of view. Given the overall DARPA mission to pursue high risk, high payoff R&D, it is incumbent upon top management, including the Office of the Director and the Program Management Office, to plan and be prepared for the possible occurrence of significant cost growth in on-going DARPA programs. The most effective way to satisfy this requirement is through the establishment and management of a program risk budget controlled by the Director.

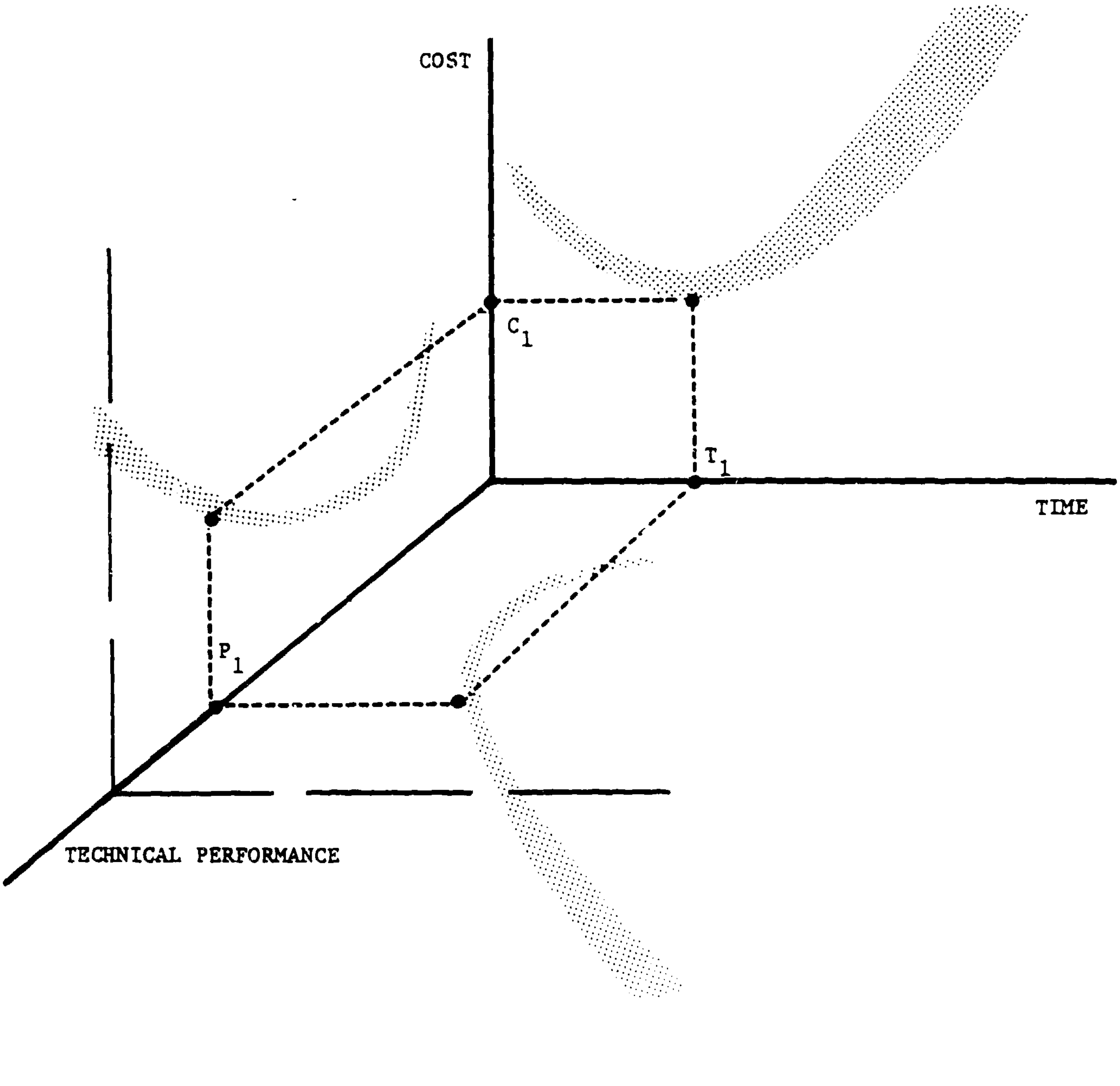
The objective of the effort documented in this report is to develop a set of analytical techniques which can be used as the basis to identify a management structure and set of procedures to be implemented by the Program Management office through which such a budget can be established and controlled. This management process has been designed so that minimal additional requirements for data and reporting would be placed on the technical program offices. In addition, it is anticipated that implementation within the Program Management Office could be achieved using information available from management systems currently in place or under development and that operation would place little or no additional workload on the limited staff resources of the Office. The overall process, described in detail in Section II, is an iterative, interactive one in which an initial aggregate level of funding for risk is established and subsequently adjusted and allocated among selected programs based on a systematic process to assess relative cost and schedule risk within them. The remainder of this section will provide a brief description of risk and cost growth in government R&D programs and relate this environment of uncertainty to the context of the DARPA mission.

## C. BACKGROUND

### 1. General

The pervasiveness and magnitude of uncertainty and risk in government R&D programs and its impact on cost overruns and schedule slippages is widely recognized. Conceptually, these relationships can be depicted as in Figure I-1. Although the interaction among technical performance, cost, and schedule may appear intuitively obvious, quantification of such relationships to the point that accurate predictions for a specific R&D program can be performed is a difficult task. Design of specific models is necessary to develop the cost-performance curves. Likewise, networks identifying critical activities and

FIGURE I-1. THEORETICAL RELATIONSHIPS AMONG TECHNICAL PERFORMANCE, PROJECT DURATION AND PROJECT COST



their associated durations, prerequisites and costs are required for cost-schedule and performance-schedule trade-offs. Within DARPA, as development of technical programs proceeds, additional information, including design models and networks can become available to allow a better understanding of the shape of the curves and the trade-offs among variables. As risk analyses continue, more information on which to postulate the width of the bands can also be developed. However, at the inception and early phases of such programs (at a time when initial cost estimates are made and funds committed), the data necessary to construct these curves or the bands of uncertainty around them for any program are typically not available.

Nonetheless, it is possible to discuss the impact of schedule and performance variations in terms of implications for project cost. Using the potential for cost overrun as an indicator of risk addresses a major concern of DARPA management - the ultimate cost to completion. Significant cost overruns, while not unusual for recent Federal R&D programs, could prove critical; and unacceptably high overruns could lead to the cancellation of a project. This concern for anticipating and preventing cost overruns is validated by the experiences of other technology development programs.

There is significant empirical data to document the extent of cost overruns in Federal R&D programs. Statistical analyses of the extent of cost growth in a large number of programs were presented in the Interim Progress Report. The data used for this quantification came from a comprehensive data base developed by the Meridian Corporation. Portions of this data are recorded in Appendix A, summarizing combined military and civil major acquisitions for the primary purpose of disclosing the financial status of major Federal programs. Included in this data are acquisitions either in the development, test, production or construction phases. Major programs as defined by the Department of Defense include those in excess of $75 million; civil projects are those in excess of $25 million.

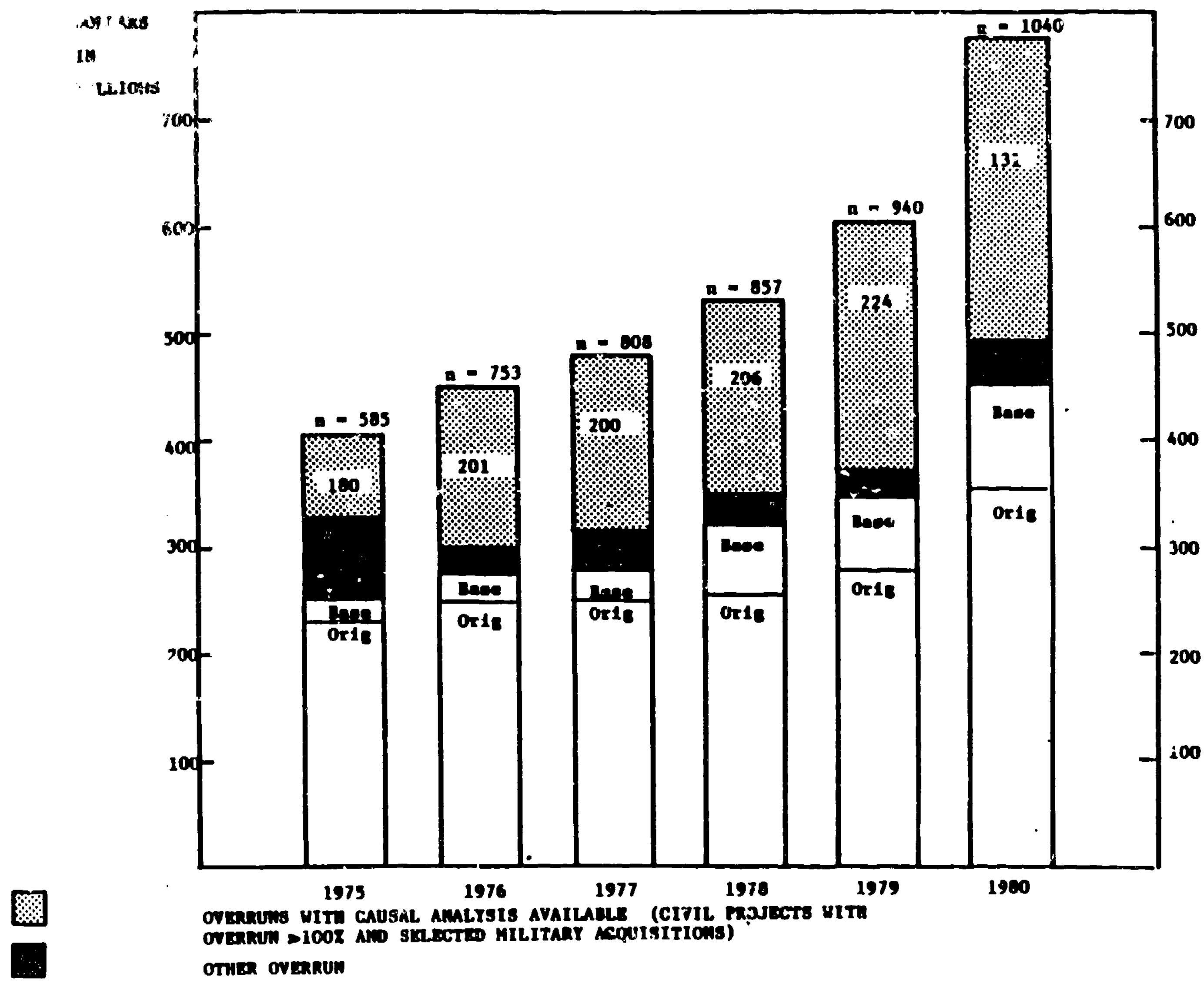
Figure I-2 shows the cost growth in civil and military acquisitions since 1975. Persistent cost growth is reflected in the shaded areas which depict the differences between the current cost estimate and the planning estimates for the projects included in each year's data. The original estimate was defined as the estimate used for program planning. The baseline estimate is the estimate at the beginning of development. The current estimate is the most recent estimate available in each year. In Figure I-2, "n" represents the total number of major acquisitions for that year. For example, in 1980 there were 1040 total projects examined. Significant cost growth occurred in 131 of those projects. The reasons for overruns in these projects are further discussed below and depicted in Figure I-3.

The collected data have been analyzed in terms of causes of cost growth for civil acquisitions having 100 percent or more increases and selected military acquisitions. The cost increases are attributed to the following seven factors:

1. Quantity - changes including scope.
2. Engineering - changes altering a system's established physical or functional characteristics.
3. Support - changes involving spare parts, ancillary equipment, warranty provisions, and government-furnished property or equipment.
4. Schedule - changes in delivery schedules, completion date or some intermediate milestone of development, production or construction.
5. Economic - changes that are influenced by one or more factors in the economy, such as inflation.
6. Estimating - corrections or other changes occurring since the initial or other baseline estimates for program or project costs.
7. Sundry - changes other than the above categories, such as environmental costs and relocation assistance for water and highway projects.

FIGURE I-2

**COST GROWTH IN CIVIL AND MILITARY ACQUISITION**




OVERRUNS WITH CAUSAL ANALYSIS AVAILABLE (CIVIL PROJECTS WITH OVERRUN >100% AND SELECTED MILITARY ACQUISITIONS)

OTHER OVERRUN

FIGURE I-3

**RELATIVE IMPORTANCE OF CAUSES OF COST OVERRUNS IN MAJOR SYSTEMS ACQUISITIONS**

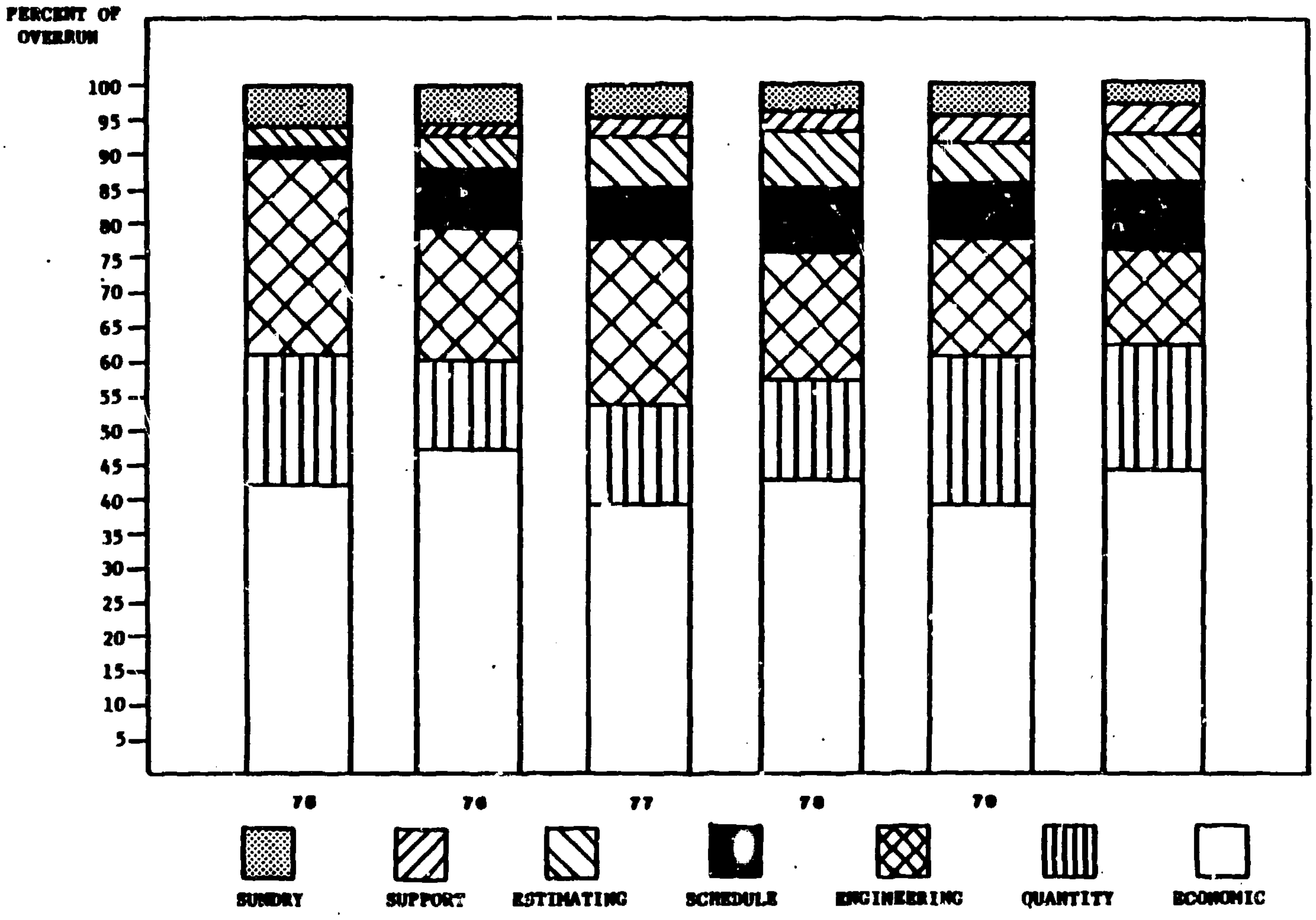


Figure I-3 illustrates the relative impact of these seven GAO causal factors on cost overruns in Federal major systems acquisitions.

Taken together, these two figures illustrate several important points of interest to DARPA management. First, the evidence over time points to a growing inability government-wide to accurately predict or avoid significant cost overruns. This trend persists for all classes of high technology programs in defense, energy, and space applications. Analyses of these overruns of the type generally depicted in Figure I-3 indicate that all three of the key variables shown in Figure I-1 -- cost, schedule, and technical performance -- are highly inter-related. However, the complexity of these relationships has prevented the isolation of causal factors and quantification of simple analytical predictors. Nevertheless, due to the large available data base, the concept of cost growth risk provides the best overall indicator of program risk for management. This concept and its detailed quantification for DARPA were fully described in the Interim Progress Report. Its application to the task of developing an on-going risk management process for DARPA management is described in Section II.

2. <u>Implications for DOD and DARPA</u>

The general problem of risk assessment is especially germane to DARPA management at this time. In April, 1981 the Deputy Secretary of Defense promulgated a set of thirty-one recommendations to modify and improve the efficiency of the defense acquisition management and procurement process.* Among these recommendations were several that relate to risk management and assessment. Recommendation No. 6 suggests that the Services be required "to budget to most likely or expected costs, including predictable cost increases

*Department of Defense Memorandum, April 30, 1981.

due to risk." Recommendation No. 11 provides that there be "Increase[d] DoD efforts to quantify risk and expand the use of budgeted funds to deal with the uncertainty." Both of these recommendations are consistent with DARPA's role as the DoD agent responsible for investigating the potential of long term, innovative, technologically advanced concepts to national defense requirements. As such, DARPA sponsors programs to proof of concept which are inherently subject to a high degree of technical risk and uncertainty. In particular, in recent years, DARPA has been sponsoring programs which involve prototype hardware systems development and experimentation. These programs [e.g., the DARPA Program Element entitled Experimental Evaluation of Major Innovative Technologies (EEMIT)] tend to involve relatively large annual budgets and are subject to a great deal of uncertainty in cost estimates. As such, they are primary candidates for application of an on-going risk assessment and management process within the agency.

# II. MANAGEMENT PROCESS DEVELOPMENT

## A. DARPA REQUIREMENT

Explicit OSD direction and DARPA's growing involvement in high risk, high visibility, hardware development programs virtually dictate a requirement for a system of risk assessment and management applicable to the EEMIT programs. Following both logic and OSD direction, the DARPA goal, as a first step, should be the establishment of a "risk budget" for the EEMIT programs. The DARPA Program Management Office (PMO) currently mantains a system of cost growth monitoring that can serve as the administrative and philosophical foundation for a justified and flexible risk budget. A systematic program of risk assessment and risk management could result in the establishment of relative levels of program risk, or alternatively levels of confidence of cost overrun avoidance. These risk, or confidence levels may then be used to establish a justifiable allocation of funds into the desired risk budget.

While using the philosophy of "budgeting for risk," there is a requirement to clarify the relationship between overall program risks and budgeted funds. Generally, program risks are reduced to three broad categories - cost, schedule and technical (or performance) risk. Technical risk is difficult to measure prior to certain program milestones and testing of the "product", and then performance measurements are usually program-unique and may not be directly compared with dissimilar technologies. Similarly, schedule risk is intimately related to both cost and technical risk, and quite difficult to measure or predict independently prior to the occurrence of an actual slippage. It is also recognized that cost risk, schedule risk and technical risk are to some degree interdependent in all programs, but that due to statistical uncertainty the interrelationship is rarely quantifiable or functionally specific. The accepted "common denominator" measure of program efficiency is cost. One may rationally argue that, in general, realized schedule and technical risks will ultimately generate cost increases or overruns of predicted budget level requirements.

Cost risk, or more specifically, "cost-growth" risk may therefore be considered a fairly representative and accurate indicator of overall program risk, directly relatable to a "risk budget." This does not imply that potential variances in schedule and performance objectives should not be monitored as lead indicators of cost growth.

Having determined that cost-growth risk may be used as an operative measure of relative program risk or confidence to be used initially in establishing a risk budget, a quantifiable measure of risk and/or confidence level is required. Additionally, practical experience and the historical record demonstrate that program risk is a dynamic variable and must be monitored and reassessed in an interative manner throughout the duration of each program if the PMO is to have the capability to manage the risk and balance the risk budget between programs. There is therefore a need for an iterative and program interactive process of risk assessment and management.

## B. RELATIVE MEASURE OF RISK/CONFIDENCE

The major preliminary requirement for the establishment of the desired risk assessment and management process is a definitive measure of risk or confidence level. A "cost-growth risk" relationship has been developed which provides a relative, but quantitative, measure of risk based on the historical experience of major high technology programs in DOD, DOE, NASA and DARPA. This relationship was established by detailed analysis of available government-wide (including DARPA) data on program cost estimates, their iterative growth and actual realized costs.

Initial analysis of the data base resulted in the determination that the relevant measure of cost-risk was not, in fact, the risk of the occurrence of a cost overrun, since virtually all programs in the data base experienced repetitive yearly cost overruns. The relevant measure of program risk is rather the risk of additional "cost-growth" once a cost overrun has been predicted, or the occurrence of significant overruns in any given program assumed. This is in line with the basic OSD direction, that assumes some overruns are inevitable due to the inherent "risk" in high technology programs, and that "risk" must be quantified and budgeted for, i.e. determine the total potential amount of overrun, budget for it, and control it as it occurs.

The overrun data in the DOD-DOE-NASA portion of the data base was treated independently of the DARPA data to determine the consistency of the smaller DARPA base with the larger and more statistically valid government-wide data base.

The data base was first subjected to "delphic" analysis to segregate "high," "medium" and "low" risk programs, based on technology application. High and medium risk programs for FY '77, '78, '79 and '80 were examined in detail. Overrun magnitude was represented in dimensionless "cost factor" form, that is the ratio of the year-end estimate, or actual cost, to the original program baseline cost prediction for that year. After eliminating obviously discrepant data points such as those known to relate to program cancellations, over six hundred usable cost factors were obtained.

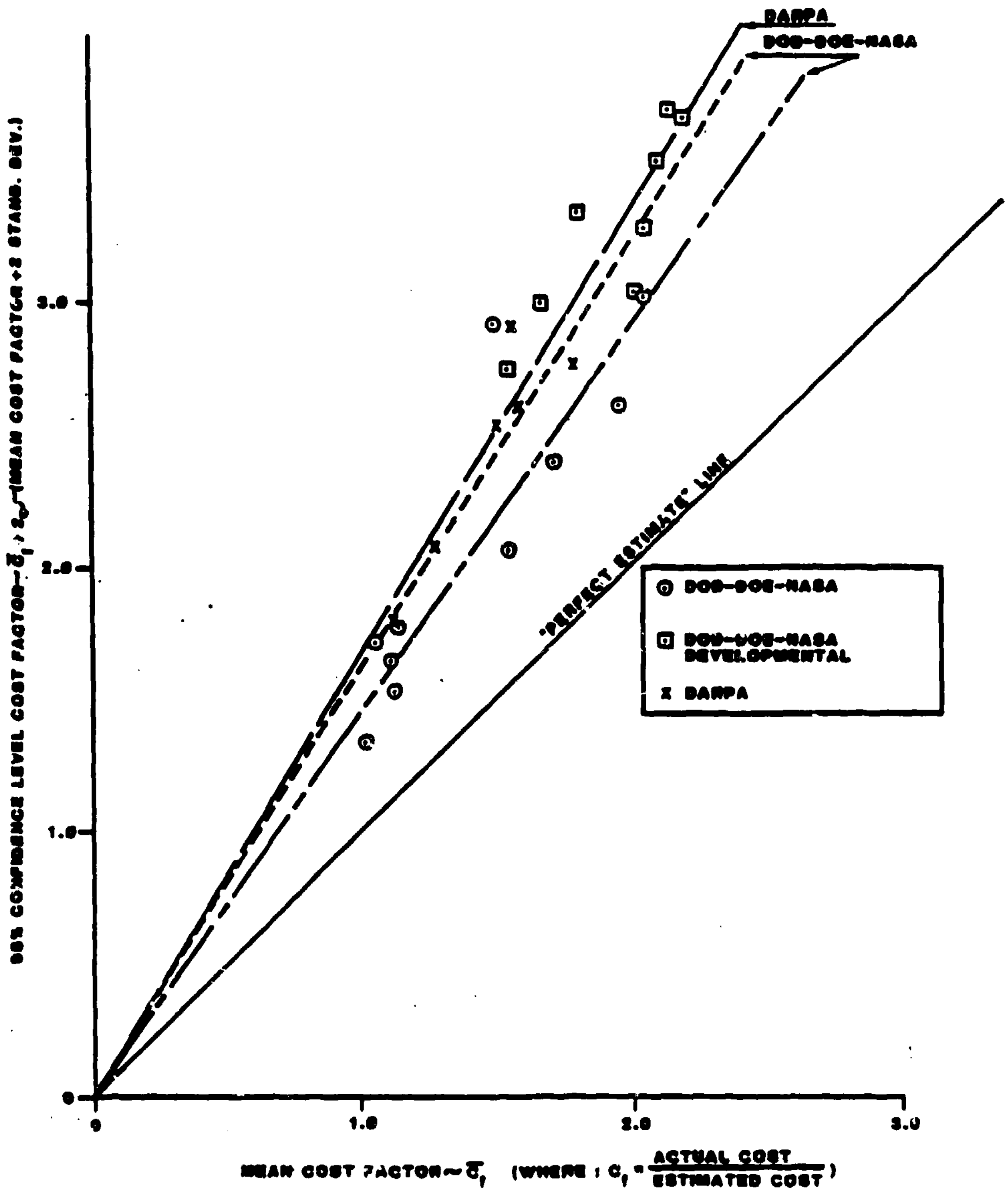
An analysis was conducted to determine the natural aggregations, or groupings of the data points to determine if there were significant causal factors of overruns evident in the data base. The results of this effort were generally negative, as there were no obvious groupings of data by program type (aircraft, ship, satellite, etc.) or technology level, or even agency.

However, displaying the data by "spectral density" (in a one-dimensional plot of cost factor magnitude) for each fiscal year, resulted in a consistent progression of aggregations of closely bunched data points. Using the statistical relationships for the "normal distribution," the mean value, and standard deviation were calculated for each data aggregation. This resulted in ten statistical data points. Since the value for twice the standard deviation is representative of a probability of non-occurrence of 97.5%, this value was considered representative of a confidence level of non-occurrence of cost-growth of approximately 100%, when added to the mean value. Simply stated, for a cost overrun predicted to be at the mean value, one could be 97.5% certain that the actual overrun would not exceed the mean value plus twice the standard deviation, based on statistical analysis of the historical data base. This relationship is plotted in Figure II-1 as "DOD-DOE-NASA" data represented by circular data points. Eight additional statistical data points were developed by this process from the DOD-DOE-NASA data base from those programs where the components of the cost overruns were listed in the data baes. In this case "quantity" and "production" components of the overruns were deleted in calculating the cost factors, resulting in data more representative of overruns incurred in developmental programs. These data are represented as squares in Figure II-1 labeled "DOD-DOE-NASA developmental." These two sets of data resulted in a definitive and credible cost-growth risk trend represented by the lower dashed lines in Figure II-1.

Next the available DARPA EEMIT data base was processed in the same manner as the previous sets, with the exception that the cost factors were formed exclusively of the ratio of <u>actual overruns</u> to predicted overruns. The DARPA statistical aggregations are represented by "X"'s in Figure II-1, and are highly consistent with the DOD-DOE-NASA data and experience, with the bias toward developmental programs, as would be anticipated. The trend displayed, and the

FIGURE II-1

## COST GROWTH RISK~DOD-DOE-NASA/DARPA CORRELATION



selection of a "cost-growth risk" relationship as the relative measure of risk or confidence level appear to be totally applicable to DARPA EEMIT program experience. For the DARPA EEMIT data the uppermost dashed line of Figure II-1 is representative of the "100% confidence level of cost growth avoidance" or alternatively, "zero risk of cost growth." Graphically, this can be interpreted as follows (in Figure II-1) given a predicted cost increase of say, 50%, resulting in a cost factor of 1.5, selecting 1.5 on the horizontal axis, proceeding vertically to the "DARPA" line, and then horizontally to the vertical axis and a value of approximately 2.5, signifying that with a predicted cost increase of 50%, statistical cost-growth experience indicates that "risk budget funds" of 150% would be required to provide 100% confidence of not realizing an actual cost overrun. Application of this relationship to the formulations for the "normal distribution" provides the "cost-growth risk" relationship whereby entering a risk fund amount (in percentage or decimal value) the level of either "confidence of cost growth avoidance" or "cost growth risk" will be obtained (again in dimensionless form).

The cost-growth risk relationship will be used throughout the proposed risk assessment and management process as the "relative measure of risk" whereby risk and/or confidence levels will be expressed, providing the unifying measure of effectiveness for the analysis.

## C. INITIAL RISK BUDGET

The establishment of an initial "justified" risk budget for EEMIT programs is a necessary prerequisite to the proposed process of risk assessment and risk management. Initial levels of confidence must exist as relative measures, or targets, which the risk analysis and management phases will ultimately refine and develop into firmly justified risk budget allocations. The initial risk budget (or risk fund allocation) will be established by the Program Management Office (PMO) and the Director for the POM.

Distribution factors based on program funding profiles are then established. Each program is allocated a distribution factor equal to the decimal value of that program's fractional share of the total EEMIT budget. The total EEMIT risk fund is then multiplied by each distribution factor (decimal value) producing a risk budget for each program based solely on budget share.

Similarly, multiplying each program's POM year budget values by this distribution factor will result in the program risk budget distribution across the POM, again based solely on budget share and distribution per year.

Since it is recognized that many factors other than budget share will be influential in determining the desired confidence level (risk fund allocation) for a program, influence factors based on non-specific program characteristics will be determined by consensus review of competing EEMIT programs by the Directors of the six DARPA "Technology" Offices or their designated representatives. The six Directors or their representatives will be afforded the opportunity to review the EEMIT programs during a dedicated series of briefings by the program managers.

After the briefings the Directors will be allowed two weeks in which to evaluate all the EEMIT programs on evaluation sheets issued by the PMO.

The evaluation sheets will define rating categories for the programs such as -- political impact -- operational potential -- technical uniqueness -- existing requirement -- program longevity -- "personal preference" -- and any other categories desired or preferred by the PMO. Each rating category will be assigned a numerical decimal value between zero and one by each Director for each EEMIT program. The values for each program will be added and non-dimensionalized into an overall decimal value on each rating sheet, and all the sheets for each program in turn averaged into a representative decimal value for that program.

With this "influence" factor established for each program, it will then be multiplied with the previously determined funding profile distribution factor for that same program.

The resulting combined factors are then non-dimensionalized by dividing each of them by the sum of all the combined factors resulting in a set of "adjustment" factors for risk fund distribution, each of which has a decimal value less than one, and the sum of which is equal to one.

The adjustment factor for each program will then be multiplied by the overall EEMIT risk fund to obtain that program's risk budget, and by each program's yearly POM budget to obtain the yearly allocation of risk budget within the program, now based both on "distribution" and "influence" factors.

The resulting allocation of the overall risk fund is the "initial risk budget," justified both by funding profile and subjective judgment.

## D. THE RISK ASSESSMENT AND MANAGEMENT PROCESS

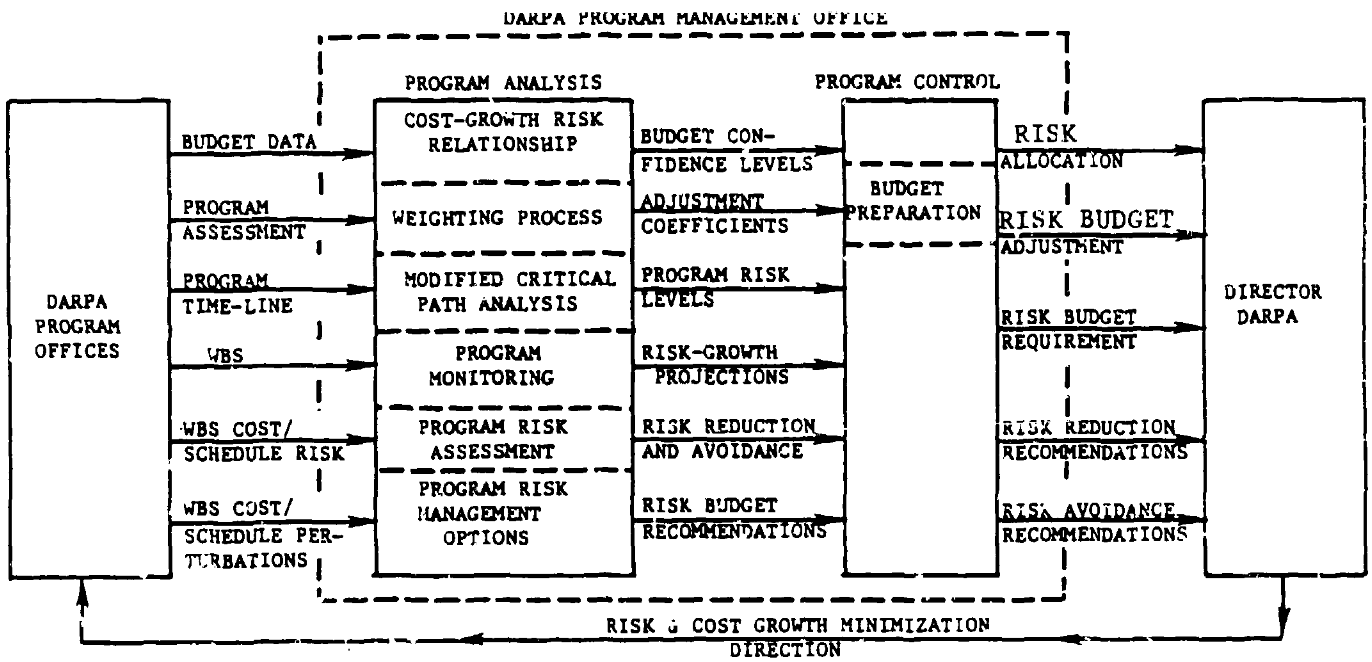
Once the initial risk budget has been established for all (or selected) EEMIT programs, a continuing flow of information will occur from the DARPA Program Offices to the Program Management Office then on to the Director and finally back to the Program Offices. The following is a step-by-step description of the program illustrated in Figure II-2.

The Program Offices will provide the Program Management Office with:

- program funding profiles
- program work breakdown structures (WBS)
- program time-line milestone networks
- assessments of percentage cost and schedule risk for each WBS element at level 3 (this risk assessment will originate at the management level most directly responsible for each WBS element assessed)

FIGURE II-2

RISK ASSESSMENT AND MANAGEMENT PROCESS



- timely prediction of the extent of any anticipated cost or schedule "growth" associated with each WBS level 3 element

- extent of any cost or schedule growth in each WBS level 3 element when it/they occur

The Program Management Office will have at hand:

- an established and justified risk budget based on the most recent POM submission for the EEMIT programs

- an established "cost-growth risk" relationship based on the DOD-DOE-NASA cost overrun experience as it relates to the DARPA cost overrun history

- established levels of "confidence of cost overrun avoidance" (confidence levels) for each EEMIT program each POM year, derived by applying the cost-growth risk relationship to the risk budget

The Risk Assessment/Management Program will then be conducted by/for the Program Management Office.

The program time-line milestone network will be combined with WBS level-3 elements into a "modified critical path" (MCP) network, wherein each element has an associated level of cost and schedule risk provided by the Program Office.

The initial inherent program risk level will then be established by mathematically combining and/or compounding the initial WBS risk levels along the MCP network, as well as "escalating" or "deflating" any WBS estimates that are obviously inconsistent with the rest of the program or past experience, using the cost-growth risk relationship.

The initial program risk level will then be compared with the established budgetary confidence level for each program year.

This process, when repeated for all EEMIT programs will give the first indications of the adequacy and balance of both the initial and subsequent risk budgets.

When cost overruns are predicted they will be projected into the MCP and their potential impact on program confidence levels established, both at the level of overrun predicted and at an escalated "worst case" level established from the cost-growth risk relationship.

The same process would, of course be repeated for actual cost overruns at the WBS level 3 in the MCP and the decrease in relative program confidence level (established by the allocated risk budget) determined.

Similarly, both predicted and realized schedule overruns (extensions) would be projected into the MCP network in the same manner as cost, but without "worst-case" escalated values, and resulting in an assessment of risk of meeting program time milestones.

When either projected or actual cost or schedule overruns threaten to increase overall program risk beyond budgeted levels, the MCP and WBS will be analyzed for potential risk reduction and/or risk avoidance options such as alternate time-line paths or WBS element phasing.

Risk reduction options so determined will then be recommended by the Program Management Office directly to the program manager, or indirectly through the Director, and the six Technology Offices.

When projected program cost risks threaten to exceed the budgeted confidence levels, the projected risk for all programs must be examined and the risk budget allocations readjusted or increased to retain desired program confidence levels.

While the described risk analysis and management process is essentially continuous and iterative, a "formal" exercising of the system is recommended at least bi-annually, timed to the POM cycle.

This process can potentially provide responsive iterations of the risk budget whenever required as well as interactive risk avoidance and reduction initiatives between the Program Offices and the Program Management Office, and "real time" projections of overall program risk levels.

# III. SUMMARY AND CONCLUSIONS

## A. THE DARPA REQUIREMENT

By its very nature, DARPA has an inherent need for a system of risk assessment and management. DARPA exists primarily to manage those high risk, high potential pay-off programs that could not survive budgetary scrutiny in the research and technology elements of the individual services. Over the years DARPA has been highly successful in the harvesting of high pay-off technologies while weathering the attendant high risk. This relative success has resulted in DARPA programs growing from the arena of generalized technology exploitation into the multiple technology, prototype-oriented and highly visible world of present EEMIT programs. OSD's explicit direction to identify, budget for, and minimize risk is particularly appropriate to DARPA, since over the years that agency has, in effect, been the DOD specialist in the management of high risk programs. The analysis conducted of the historical cost overrun data base indicates that DARPA's experience has been statistically comparable to other agencies dealing with high technology development. It follows that DARPA should be the DOD leader in developing practical risk assessment and management techniques in response to the OSD direction.

The process of risk assessment and management described in this report will provide DARPA with the ability to develop a justified and flexible risk budget unifying and balancing the requirements of its critical EEMIT programs, minimizing the cost overrun potential and associated program failures.

## B. THE PROGRAM MANAGEMENT OFFICE REQUIREMENT

The overall management of risk within an agency can be approached from two perspectives, either "bottom-up" or "top-down." In the "bottom-up" approach, risk assessment and management procedures would be implemented independently by each program manager, based on his unique needs and perceptions. Ultimately, the risk assessments produced in this manner would surface as part of each program's budget requirement, hopefully identified and justified as "risk budget." Top-down risk management would originate in the agency's senior management level. A common procedure for risk assessment and management would be developed, as in DARPA's case, by the Program Management Office, and implemented in all programs with common data reporting requirements and milestones. The resultant overall assessment of risk could then be used to implement a flexible risk budget. Iterative assessments of risk in each program could then be used to continually balance requirements between programs in accordance with agency-wide priorities, resulting in true risk management and a minimized risk budget.

The risk assessment and management process described in this report would provide the Program Management Office with all the advantages of a top-down system, while the individual program offices retain their necessary element of internal control by providing the initial risk assessments at the WBS-3 level and the time-line network, as well as the opportunity to predict cost and schedule changes potentially resulting in additional resources. In essence, the proposed system will manage <u>only</u> risk and will <u>not</u> preempt the program managers' functions.

Additionally this process will provide the Program Management Office with the opportunity to participate in the establishment of inter-program priorities. With this insight the PMO will have the potential to identify risk causal factors as they emerge, as well as risk avoidance and reduction alternatives. This inter-program overview will provide the PMO with the capability to recommend risk management actions to the Director which would reduce risk and minimize the cost overrun potential for the overall EEMIT program.

# APPENDIX A

## COST-GROWTH RISK RELATIONSHIP

## COST-FACTOR DATA

## GROUP I
HIGH RISK PROGRAMS
COST FACTOR RANGE IN 0.5 TO 1.5

| DOD | '77 | '78 | '79 |
|---|---|---|---|
| DEF Satellite Comm. System | 1.0 | .77 | .95 |
| IIR Maverick | .98 | 1.10 | 1.17 |
| Laser Maverick | - | .91 | - |
| TR-1 | - | 1.0 | 1.06 |
| DIVAD Gun | 1.0 | 1.03 | 1.04 |
| AALC (Air Cushioned Vehicle) | - | 1.003 | - |
| F-18 | .99 | 1.11 | 1.87 |
| Tomahawk (SLCM) Missile | .73 | 1.06 | .64 |
| AN/TTC-39 Communications Switch | 1.36 | 1.37 | 1.21 |
| Cannon Launched Guided Projectile | .89 | .98 | 1.11 |
| Patriot Missile (SAM-D) | 1.13 | 1.19 | 1.07 |
| YAH-64 | 1.08 | 1.10 | 1.32 |
| CVN-68 Class Aircraft Carrier | 1.32 | 1.36 | 1.36 |
| LAMPS MK III | 1.08 | .90 | .92 |
| MK-48 Torpedo | 1.02 | .98 | .97 |
| PHM Ship | .54 | .54 | .55 |
| TACTAS | .75 | .77 | 1.64 |
| **DOE** | | | |
| Fast Flux Test Facility | - | 1.0 | 1.0 |
| 4.8 MW Fuel Cell Demonstration Unit | 1.0 | 1.28 | 1.28 |
| Fixed Bed Synthetic Oil Process Development Unit | 1.0 | 1.004 | - |
| Pressurized Fluidized Bed Combined Cycle Plant | 1.0 | .97 | 1.18 |
| 14 MEV Intense Neutron Source Facility | 1.0 | 1.0 | - |
| Confinement System Poloidal Diverter Experiment | - | 1.0 | - |
| High Energy Laser Facility | 2.41 | 1.16 | 1.16 |

| DOE | '77 | '78 | '79 |
|---|---|---|---|
| Mirror Fusion Test Facility | - | 1.0 | 1.0 |
| Tokomak Fusion Test Reactor | 1.11 | 1.11 | 1.33 |
| Intersecting Storage Accelerator, 400 GFV Electron Volts | | 1.0 | 1.0 |
| Position - Electron Joint Project | 1.0 | 1.0 | 1.0 |
| High Energy Laser Facility (CA) | 1.25 | 1.0 | 1.0 |
| 10 MW Central Receiver Solar Power Plant | 1.0 | 1.02 | 1.0 |
| 200 BEV Accelerator | .97 | .97 | - |
| High Btu Synthetic Pipeline Gas Demonstration Plant | 1.0 | 1.0 | 1.15 |

CF DISTRIBUTION

| YEAR | SAMPLE | MEAN | S DEV | S DEV TIMES TWO |
|---|---|---|---|---|
| 77 | 25 | 1.06 | .33 | .66 |
| 78 | 32 | 1.02 | .16 | .32 |
| 79 | 26 | 1.11 | .27 | .54 |

## GROUP II
MEDIUM RISK PROGRAMS
COST FACTOR RANGE IN 0.0 TO 3.0

| | '77 | '78 | '79 |
|---|---|---|---|
| **DOD** | | | |
| CGN-38 Frigate | 1.57 | 1.56 | 1.55 |
| CH-53E Helicopter | 1.61 | 1.33 | 1.38 |
| DD-963 Destoyer | 1.47 | 1.61 | 1.69 |
| CH-47 Helicoper Modernization | 1.20 | 1.13 | 1.19 |
| LHA Ship | .96 | 1.14 | 1.21 |
| M-198 Howitzer | 1.80 | 1.65 | 1.47 |
| Trident Support Site, Drydock Phase I & II | 1.0 | .86 | .92 |
| Trident Support Site, Bangor, WA, Training Facility, Increment 1 & 2 | 1.11 | 1.10 | 1.17 |
| **DOE** | | | |
| High Performance Fuel Lab | 1.25 | 1.25 | - |
| Combined Cycle Test Facility | 1.0 | 1.22 | - |
| Component Development and Integration Facility | 1.19 | 1.17 | 1.17 |
| Component Test and Integration Unit | 1.0 | 1.23 | 1.4 |
| Donor Solvent Extraction Pilot Plant | 1.0 | 1.0 | 1.0 |
| Ebullated BED (H-Coal) Pilot Plant | 1.0 | 1.27 | 1.7 |
| Low Btu Fuel Car Demonstration Plant - Small Industrial | - | 1.0 | - |
| Fusion Materials Irradiation Test Facility | - | 1.0 | 1.27 |
| S8G Prototype Propulsion Plant | 1.23 | 1.23 | - |
| OTEC 1 Ocean Test Facility | - | 1.15 | .86 |
| Additional Facilities, High Level Waste Handling & Storage | 1.05 | 1.05 | - |
| Additional Facilities, High Level Waste Storage | 1.0 | 1.00 | 1.0 |
| Additional High Level Waste Storage Facilities | 1.0 | 1.0 | 1.0 |

| DOE | '77 | '78 | '79 |
|---|---|---|---|
| Additional Waste Concentration and Salt Lake Storage Facilities | .92 | .92 | .92 |
| Fluorine Dissolution Process and Fuel Receiving Improvements | 3.31 | 1.0 | 1.29 |
| High Level Waste Storage and Handling Facilities | 1.0 | 1.0 | 1.0 |
| High Level Waste Storage Facilities | - | 1.0 | 1.0 |
| High Level Waste Storage Tanks and Waste Management Facilities | 1.0 | 1.0 | 1.0 |
| Improvements to Waste Management and Materials Processing Facilities | - | 1.0 | - |
| New Waste Calcining Facility | 3.25 | 1.25 | 1.25 |
| Additional Facility for Enriched Uranium Production | 1.5 | .98 | 1.06 |
| Cascade Uprating Program, Gaseous Diffusion Plants | 1.96 | .92 | .92 |
| Centrifuge Facility Modification | - | 1.0 | 1.0 |
| Centrifuge Plant Demonstration Facility | - | 1.0 | 1.0 |
| DP Site PU Processing Facility | 2.5 | 1.0 | 1.0 |
| New Plutonium Recovery Facility | 2.97 | 1.44 | 1.54 |
| Weapons Safeguards | - | 1.0 | 1.0 |

## CF DISTRIBUTION

| YEAR | SAMPLE | MEAN | S DEV | S DEV TIMES TWO |
|---|---|---|---|---|
| 77 | 27 | 1.48 | .72 | 1.44 |
| 78 | 32 | 1.13 | .20 | .40 |
| 79 | 29 | 1.14 | .32 | .64 |

<u>GROUP III</u>

NASA PROGRAMS 1980
COST FACTOR RANGE IN 1.2 TO 2.0

| | '80 |
|---|---|
| Galileo | 1.98 |
| International Solar Polar Mission | 1.51 |
| Landsat D | 1.55 |
| Space Telescope | 1.43 |
| Space Transportation System | 1.29 |

<u>CF Distribution</u>

| | |
|---|---|
| Sample | 5 |
| Mean | 1.55 |
| Standard Deviation | .26 |
| S Dev times two | .52 |

## GROUP IV
HIGH RISK PROGRAMS
COST FACTOR RANGE IN 1.5 TO 3.0

| | '77 | '78 | '79 |
|---|---|---|---|
| A-10 Aircraft | 1.82 | 1.88 | 1.93 |
| Advanced Airborne Command Post | 1.48 | 1.55 | .98 |
| Airborne Warning and Control System | 1.32 | 1.56 | 1.56 |
| EF-111A | 1.16 | 1.68 | 1.84 |
| F-15 | 1.77 | 1.79 | 1.81 |
| F-16 | 2.28 | 2.48 | 2.49 |
| Improved Hawk Missile | 2.09 | 2.02 | 2.01 |
| Stinger Missile | 1.99 | 2.78 | 2.62 |
| UH-60A | 1.50 | 1.57 | 1.59 |
| XM-1 Tank | 1.01 | 2.17 | 2.29 |
| F-14 | 1.73 | 1.96 | 1.98 |
| PHALANX CIWS | 1.88 | 1.97 | 2.29 |
| SSN-688 | 1.84 | 1.67 | 1.88 |
| Surtass Array Sensor | 1.86 | 1.89 | 2.02 |
| Trident Sub/Missile System | 1.79 | 1.93 | 2.05 |
| Roland Missile | 1.66 | 1.90 | 2.14 |
| Sparrow AIM-7F (Navy) | 2.11 | 2.28 | 3.26 |

### CF DISTRIBUTION

| YEAR | SAMPLE | MEAN | S DEV | S DEV TIMES TWO |
|---|---|---|---|---|
| 77 | 17 | 1.72 | .34 | .68 |
| 78 | 17 | 1.95 | .33 | .66 |
| 79 | 17 | 2.04 | .49 | .98 |

DOD DEVELOPMENTAL

ADJUSTED HIGH RISK PROGRAM COST FACTOR DISTRIBUTIONS

| | '80 | '79 | '78 | '77 |
|---|---|---|---|---|
| A-10 Aircraft | 2.27 | 1.92 | 1.87 | 1.81 |
| Advanced Airborne Command Past | 2.67 | 1.63 | 1.68 | 1.60 |
| Airborne Warning and Control System | 1.62 | 1.54 | 1.54 | 1.52 |
| DEF Satellite Communication System | 1.20 | 0.95 | 0.77 | 1.00 |
| EF-111A | 2.14 | 2.55 | 1.59 | 1.14 |
| F-15 | 1.76 | 1.70 | 1.69 | 1.67 |
| F-16 | 2.20 | 1.59 | 1.60 | 1.40 |
| IIR Maverick | 1.50 | 1.13 | 1.09 | .99 |
| Laser Maverick | | 1.16 | 1.16 | |
| AIM-9L Sidewinder | | | | |
| Air Force | 3.52 | 2.93 | 2.73 | 2.62 |
| Navy | 3.90 | 2.96 | 2.83 | 2.50 |
| AIM-7F Sparrow | | | | |
| Air Force | 2.67 | 2.40 | 2.26 | 2.16 |
| Navy | 2.82 | 2.66 | 2.54 | 2.37 |
| AH-64 | 1.56 | 1.32 | 1.10 | 1.08 |
| AN/TTC-39 | 1.54 | 1.34 | 1.31 | 1.30 |
| UH-60A | 2.60 | 1.59 | 1.37 | 1.50 |
| Cannon Launched Guided Projectile | 1.45 | 1.21 | 1.08 | .99 |
| DIVAD | 1.27 | 1.02 | 1.01 | |
| Patriot (SAM-D) | 1.86 | 1.42 | 1.39 | 1.33 |
| Roland | 2.00 | 2.03 | 1.80 | 1.56 |
| Stinger | 2.13 | 2.28 | 2.39 | 1.63 |
| XM-1 Tank | 1.74 | 1.29 | 1.17 | 1.01 |
| CAPTOR | 3.40 | 4.63 | 3.81 | 3.12 |

| | '80 | '79 | '78 | '77 |
|---|---|---|---|---|
| F-14 | 1.64 | 1.57 | 1.55 | 1.32 |
| F-18 | 1.77 | 1.33 | 1.11 | 0.99 |
| LAMPS MK III | 1.38 | 0.91 | 0.90 | 1.04 |
| PHALANX CIWS | 2.65 | 2.13 | 1.87 | 1.71 |
| PHM Ship | 1.26 | 1.25 | 1.23 | 1.23 |
| Phoenix | 3.30 | 2.68 | 2.46 | 2.38 |
| SSN-68 | 1.50 | 1.46 | 1.50 | 1.44 |
| Surtass Array Sensor | 2.26 | 1.98 | 1.86 | 1.12 |
| Tomahawk | 1.23 | 1.06 | 1.07 | |
| Trident | 1.63 | 1.67 | 1.54 | 1.44 |

Cost Factor Distributions

| Range | Sample | Mean | S-Dev | S Dev Times Two |
|---|---|---|---|---|
| **1980** | | | | |
| All | 32 | 2.08 | .73 | 1.46 |
| 1.5-5.0 | 26 | 2.18 | .76 | 1.52 |
| **1979** | | | | |
| All | 33 | 1.80 | .77 | 1.54 |
| 1.50-5.0 | 19 | 2.23 | .75 | 1.50 |
| **1978** | | | | |
| All | 33 | 1.66 | .66 | 1.32 |
| 1.5-5.0 | 19 | 2.06 | .61 | 1.22 |
| **1977** | | | | |
| All | 30 | 1.53 | .61 | 1.22 |
| 1.5-5.0 | 14 | 2.01 | .51 | 1.02 |

DARPA

HIGH TECHNOLOGY-HIGH RISK PROGRAMS

| | '78 | '79 | '80 | '81 |
|---|---|---|---|---|
| Ceramic Turbine | 1.13 | 1.13 | 1.00 | 1.00 |
| | -- | -- | -- | 1.00 |
| Teal Ruby | 1.58 | 1.00 | 1.00 | 1.00 |
| | 2.51 | 2.87 | 1.25 | 1.00 |
| X-Wing | -- | -- | 1.00 | 1.00 |
| | -- | -- | 1.36 | -- |
| HIMAG | -- | 1.57 | 1.20 | 1.20 |
| | -- | 1.19 | -- | -- |
| SIAM | -- | 1.00 | 1.00 | 1.00 |
| | -- | -- | 2.10 | 2.10 |
| ACCAT | 1.00 | 1.00 | 1.00 | 1.00 |
| | -- | 2.35 | 1.08 | 1.00 |
| | -- | -- | 1.25 | 1.00 |
| Mini-Halo | -- | -- | 1.00 | 1.00 |
| Talon Gold | -- | -- | 1.13 | 1.00 |
| ALPHA | -- | -- | 1.01 | 1.00 |
| Forward Swept Wing | -- | -- | -- | 1.13 |
| Air Warfare | -- | 1.00 | 1.00 | 1.00 |
| | -- | -- | 1.00 | 1.00 |
| Anti-Armor | -- | 1.37 | 1.68 | 1.00 |
| | -- | 1.16 | 1.42 | -- |
| | -- | -- | 1.80 | -- |
| Teal Rain | -- | -- | -- | 1.02 |
| | -- | -- | -- | 1.24 |
| Assault Breaker | -- | -- | 1.01 | 1.00 |
| | -- | -- | 1.10 | 1.37 |
| | -- | -- | 1.46 | 1.53 |